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Members
USB-IF

USB 2.0 Compliance Testing

How to design, test and debug your products for success.

Jim Choate

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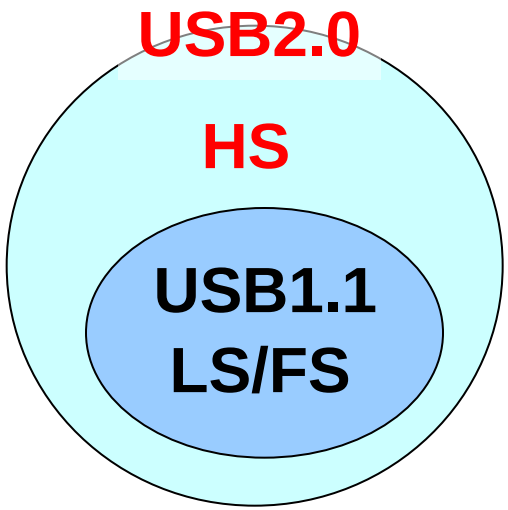
Outline

- USB 2.0 Basics
- Agilent's USB 2.0 Solution
- Design challenges
- Common compliance pitfalls
- What are Waivers?
- Advanced Debug and Testing with the 9000 series Oscilloscope
- Conclusion / Q&A

USB2.0 Basics – General

Universal Serial Bus (USB) 2.0:

- All USB specifications are owned by the USB-IF (Implementers Forum, Inc.)
- USB2.0 is an EXTENSION of USB1.1
- USB-IF states USB2.0 is the CURRENT ver. of the USB. USB1.1 is available for historical reference only.

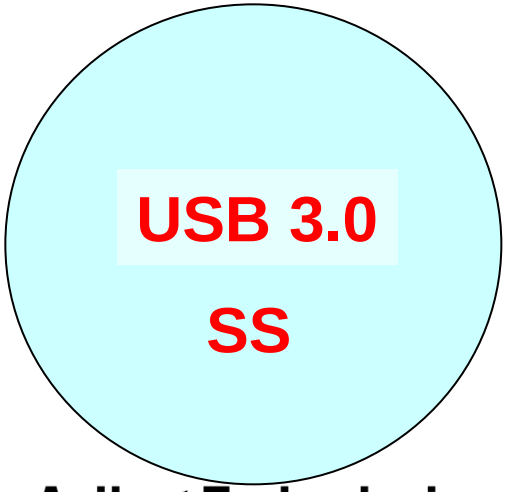


USB 2.0 Has 3 Transfer Speeds

- Low Speed (LS) = 1.5Mbps
- Full Speed (FS) = 12Mbps
- Hi-Speed (HS) = 480Mbps

USB 3.0 Has 1 Transfer Speed

- Superspeed (SS) = 5Gbps



For more details on the USB 3.0 specification refer to the webinar:
USB 3.0 Superspeed PHY Testing Challenges: Verify your 5Gbps design to the specification
http://www.techonline.com/learning/webinar/215400047

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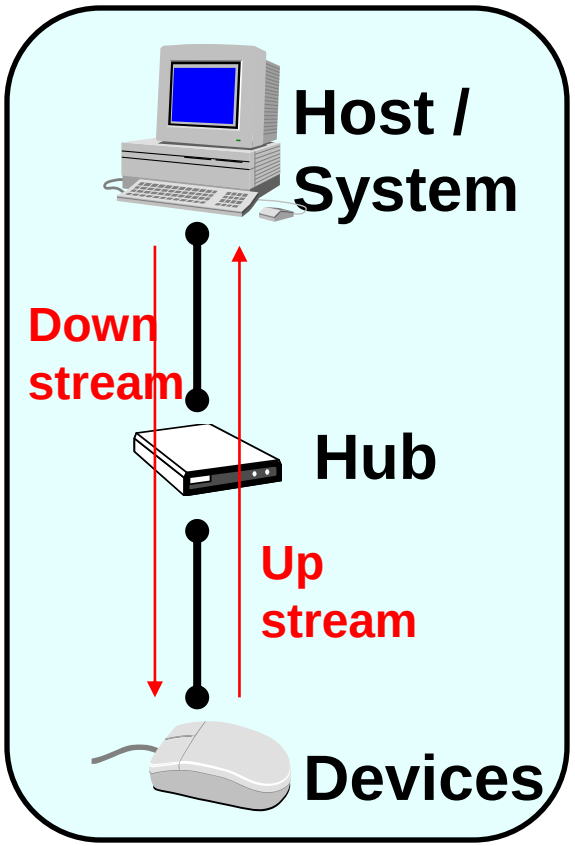
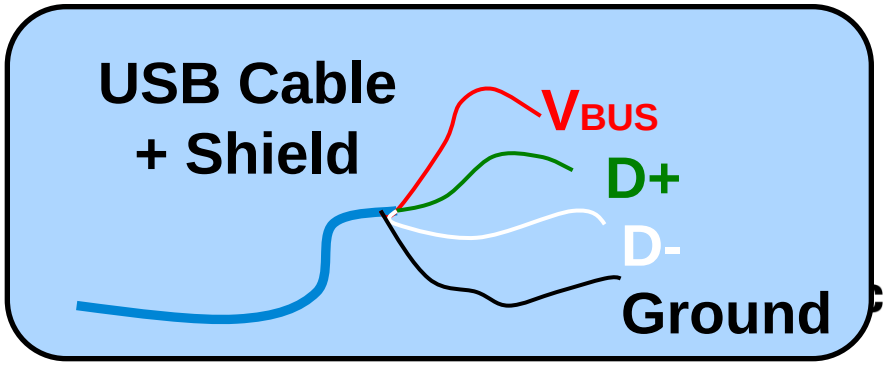
USB2.0 Basics - Architecture

- USB Architecture



- Differential Signal
- Max USB cable length of 5m
- Up to 5 Hubs
- Data from PC to the device is called Downstream
- Data from device to PC is called Upstream



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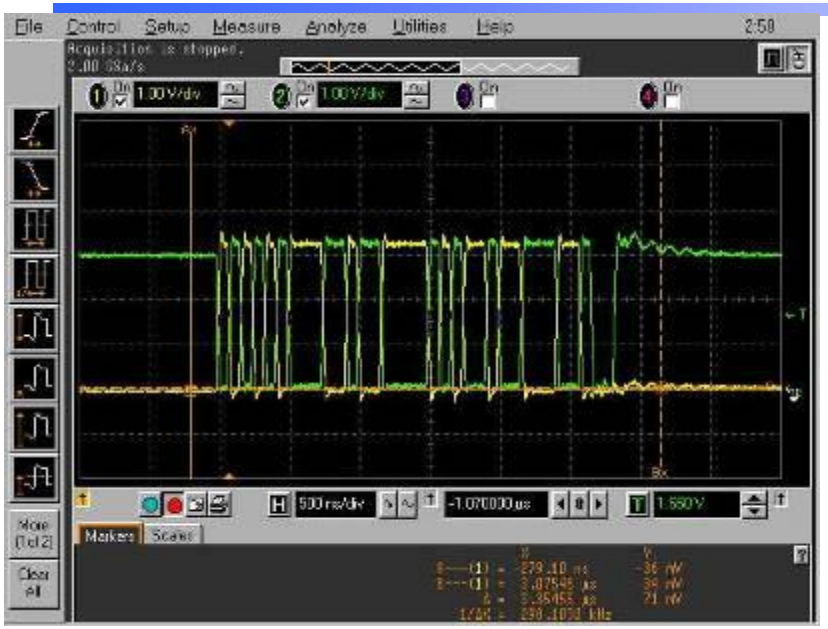
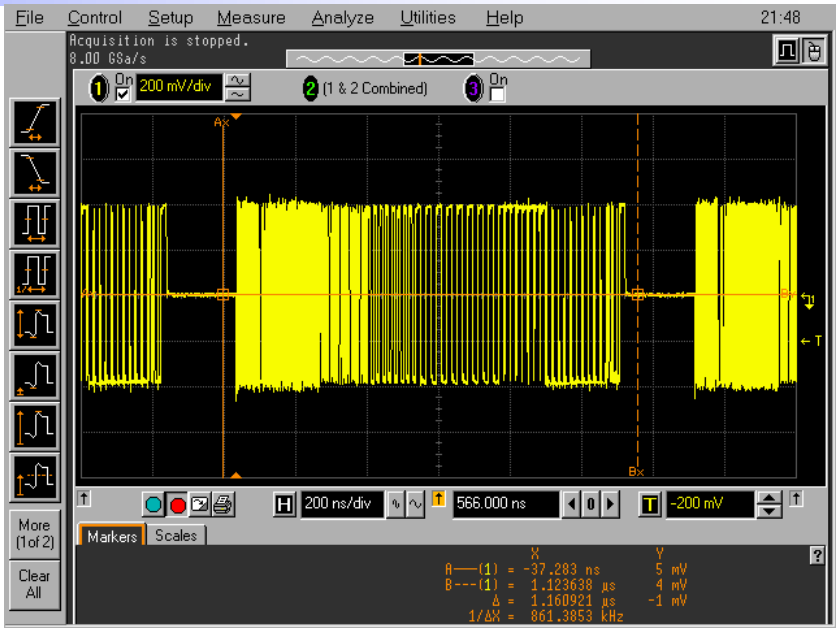
USB2.0 Basics - Signal Rates & Levels





	Low Speed	Full Speed	Hi-Speed
Sig Rate	1.5Mbps	12Mbps	480Mbps
Sig Level	3.3V	3.3V	400mV
Rise and Fall Times	75ns < Tr <300ns	4ns < Tr < 20ns	Tr > 500ps*

*High Speed USB edge rate compliance measurement method and pass/fail criteria have been changed. This will be explained in the compliance requirements section.

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Host test requirements

High-Speed System Test Requirements

The following must be successfully completed for Systems:

- Full-Speed Electrical Tests
- High-Speed Electrical Tests
- Interoperability Tests
- Functional Tests
- Submission of completed System Checklist

http://www.usb.org/developers/docs#comp_test_procedures

USB-IF Compliance Test Procedures

Compliance Test Procedures for High-Speed USB Products

Each set documents the high-speed electrical tests required for the compliance program. Please determine which set of procedures meet your need based on your test equipment choice.NOTE: Some of the following approved test solutions use proprietary software to assess signal quality and inrush current events. The only official analysis tool for certifying signal quality and inrush current is USBET20 published by the USB-IF. Please be sure to run captured signal quality and inrush current test data through USBET for an official assessment of the measurement.

USB2.0: Logo compliance for Quality

- With 480Mbps, higher quality electrical signals are essential
- The market requires all USB products meet the specification by passing the tests.

The USB 2.0 Compliance Tests are mandatory

When you pass the tests, you…

- Can use the High Speed USB 2.0 Logo
- Will be listed on the Integrator's List

The HS Logo

The FS/LS Logo

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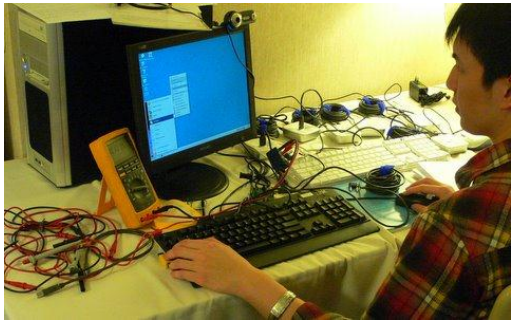
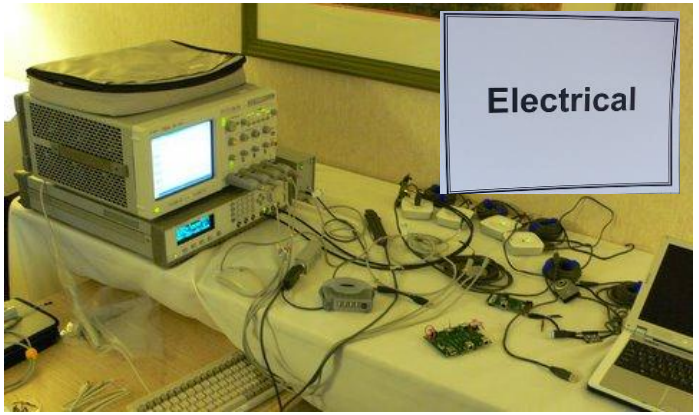
Compliance Workshop Test Suites

- USB 2.0 Interoperability Gold Suite
  - Interoperability with “gold tree” components
  - USB Command Verifier



- USB 2.0 Electrical Test Suite
  - Signal Quality Testing
  - Receiver Testing
  - Packet parameters
  - EVM Test Suites



- USB 2.0 debug suite
- 1:1 Interoperability System Suites
  - Staffed and equipped by product vendor

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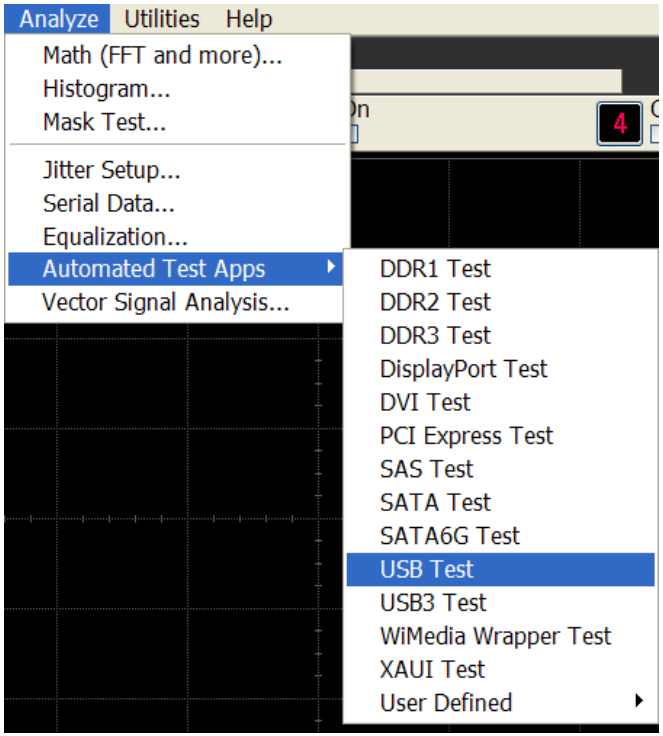
Agilent USB 2.0 Solution

- Test all aspects of your USB product using Agilent USB test solutions
- At its heart: N5416A USB 2.0 Compliance Test Software



Additional USB testing products:

- N5417A USB OTG Test Fixture
- N5464A/B USB Protocol Triggering and Decode
- E2649A High speed test fixtures
- E2646A Low/Full speed test fixture
- InfiniiMax probes
- Infiniium 90000 and 9000 series scopes

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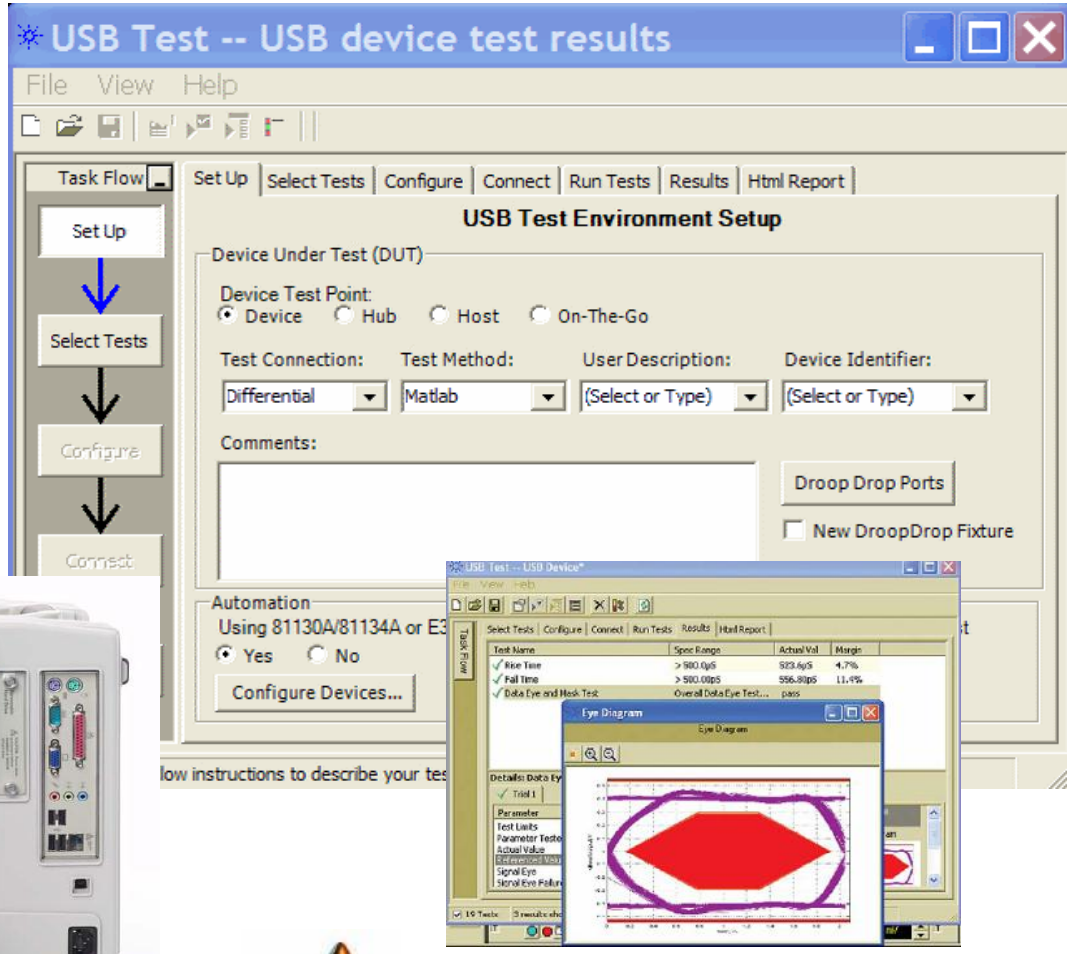
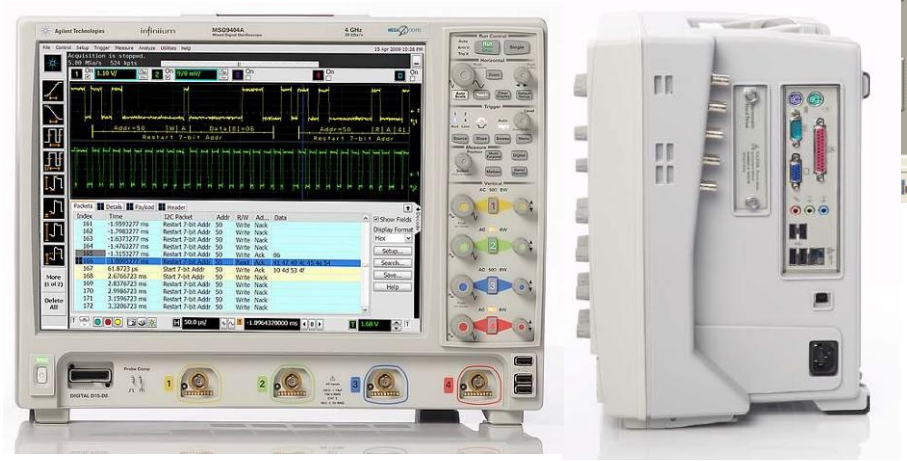
USB Transmitter testing

The worlds most popular USB test solution joins with the Infiniium 9000 series scope

- Same automation and ease of use
- NEW protocol analysis and triggering

N5416A USB 2.0 Compliance Test Application





Agilent USB-IF approved compliance test with Matlab scripts

NEW: Infiniium 9000 series Oscilloscope

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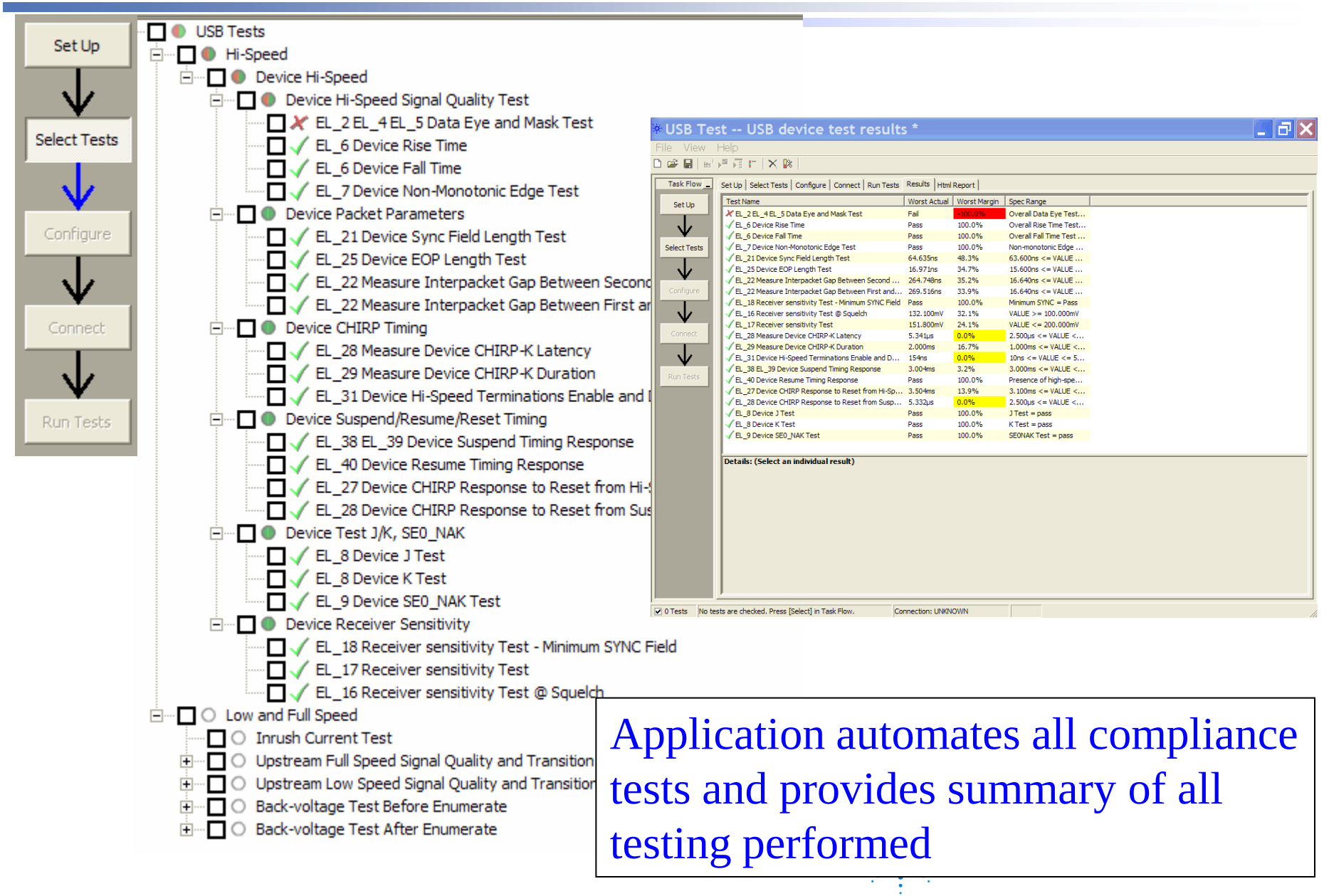
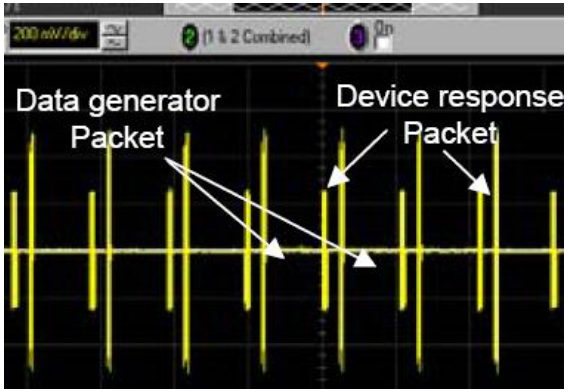
Transmitter electrical test coverage


Set Up
Select Tests
Configure
Connect
Run Tests
USB Tests
Hi-Speed
Device Hi-Speed
Device Hi-Speed Signal Quality Test
EL_2 EL_4 EL_5 Data Eye and Mask Test
EL_6 Device Rise Time
EL_6 Device Fall Time
EL_7 Device Non-Monotonic Edge Test
Device Packet Parameters
EL_21 Device Sync Field Length Test
EL_25 Device EOP Length Test
EL_22 Measure Interpacket Gap Between Second
EL_22 Measure Interpacket Gap Between First ar
Device CHIRP Timing
EL_28 Measure Device CHIRP-K Latency
EL_29 Measure Device CHIRP-K Duration
EL_31 Device Hi-Speed Terminations Enable and
Device Suspend/Resume/Reset Timing
EL_38 EL_39 Device Suspend Timing Response
EL_40 Device Resume Timing Response
EL_27 Device CHIRP Response to Reset from Hi-
EL_28 Device CHIRP Response to Reset from Sus
Device Test J/K, SE0_NAK
EL_8 Device J Test
EL_8 Device K Test
EL_9 Device SE0_NAK Test
Device Receiver Sensitivity
EL_18 Receiver sensitivity Test - Minimum SYNC Field
EL_17 Receiver sensitivity Test
EL_16 Receiver sensitivity Test @ Squelch
Low and Full Speed
Inrush Current Test
Upstream Full Speed Signal Quality and Transition
Upstream Low Speed Signal Quality and Transition
Back-voltage Test Before Enumerate
Back-voltage Test After Enumerate
USB Test -- USB device test results *
File View Help
Task Flow
Set Up
Select Tests
Configure
Connect
Run Tests
Set Up | Select Tests | Configure | Connect | Run Tests | Results | Html Report
Test Name | Worst Actual | Worst Margin | Spec Range
EL_2 EL_4 EL_5 Data Eye and Mask Test | Fail | -100.0% | Overall Data Eye Test...
EL_6 Device Rise Time | Pass | 100.0% | Overall Rise Time Test...
EL_6 Device Fall Time | Pass | 100.0% | Overall Fall Time Test ...
EL_7 Device Non-Monotonic Edge Test | Pass | 100.0% | Non-monotonic Edge ...
EL_21 Device Sync Field Length Test | 64.635ns | 48.3% | 63.600ns <= VALUE ...
EL_25 Device EOP Length Test | 16.971ns | 34.7% | 15.600ns <= VALUE ...
EL_22 Measure Interpacket Gap Between Second ... | 264.748ns | 35.2% | 16.640ns <= VALUE ...
EL_22 Measure Interpacket Gap Between First and... | 269.516ns | 33.9% | 16.640ns <= VALUE ...
EL_18 Receiver sensitivity Test - Minimum SYNC Field | Pass | 100.0% | Minimum SYNC = Pass
EL_16 Receiver sensitivity Test @ Squelch | 132.100mV | 32.1% | VALUE >= 100.000mV
EL_17 Receiver sensitivity Test | 151.800mV | 24.1% | VALUE <= 200.000mV
EL_28 Measure Device CHIRP-K Latency | 5.341µs | 0.0% | 2.500µs <= VALUE <...
EL_29 Measure Device CHIRP-K Duration | 2.000ms | 16.7% | 1.000ms <= VALUE <...
EL_31 Device Hi-Speed Terminations Enable and D... | 154ns | 0.0% | 10ns <= VALUE <= 5...
EL_38 EL_39 Device Suspend Timing Response | 3.004ms | 3.2% | 3.000ms <= VALUE <...
EL_40 Device Resume Timing Response | Pass | 100.0% | Presence of high-spe...
EL_27 Device CHIRP Response to Reset from Hi-Sp... | 3.504ms | 13.9% | 3.100ms <= VALUE <...
EL_28 Device CHIRP Response to Reset from Susp... | 5.332µs | 0.0% | 2.500µs <= VALUE <...
EL_8 Device J Test | Pass | 100.0% | J Test = pass
EL_8 Device K Test | Pass | 100.0% | K Test = pass
EL_9 Device SE0_NAK Test | Pass | 100.0% | SE0NAK Test = pass
Details: (Select an individual result)
0 Tests
No tests are checked. Press [Select] in Task Flow.
Connection: UNKNOWN

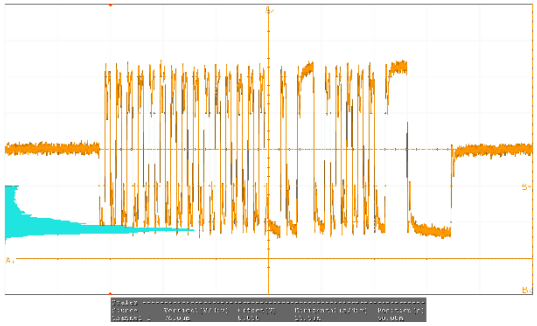
Application automates all compliance tests and provides summary of all testing performed

Receiver Testing

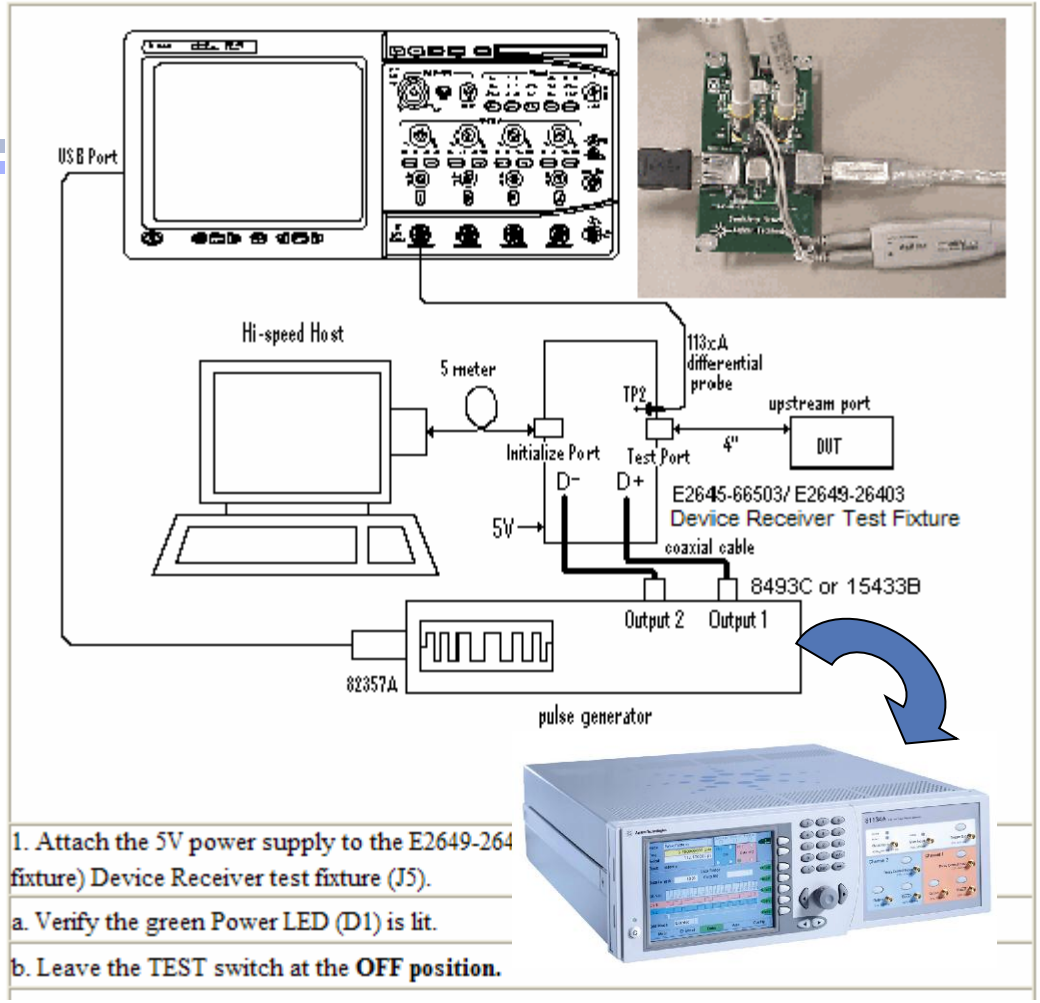
SE0_NAK Mode



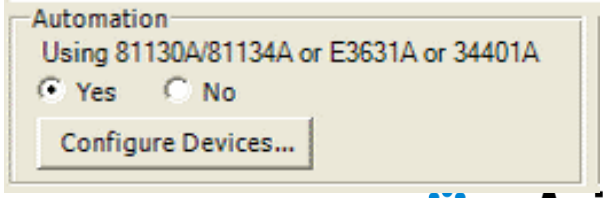
- Test mode SW places DUT into RX test mode
- Scope application auto adjusts amplitude and packet types to test RX



- N5416A USB test application measures results automatically with histogram



Connection diagrams and integrated test procedures make setup and execution of testing simple



Industries only automated RX test solution

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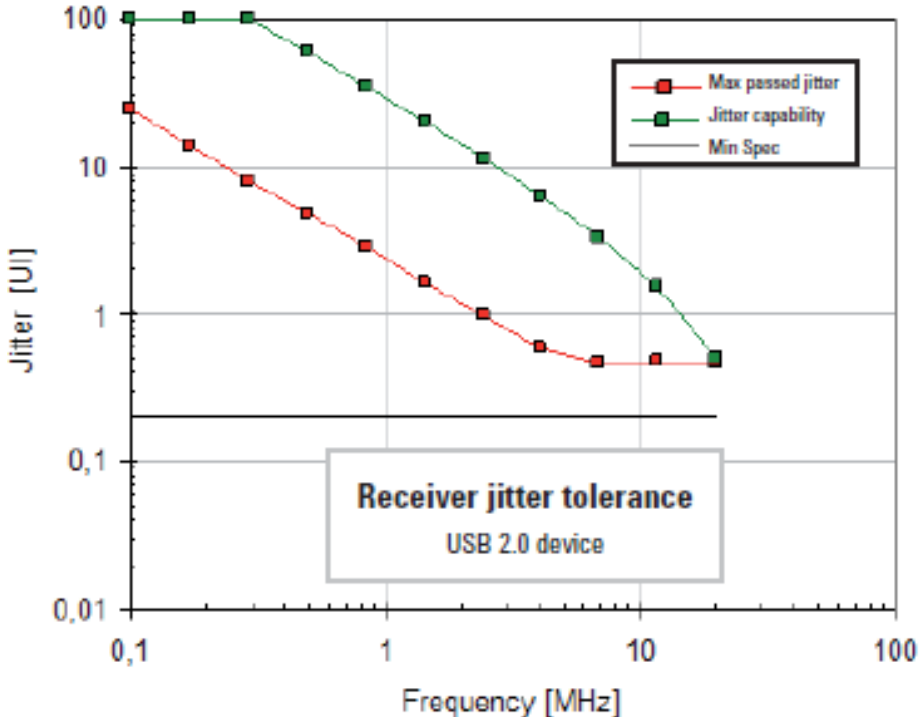
Receiver Jitter tolerance testing

- Why Test USB 2.0 jitter tolerance?
- The N5990A option 102 provides unprecedented USB 2.0 receiver device test coverage.

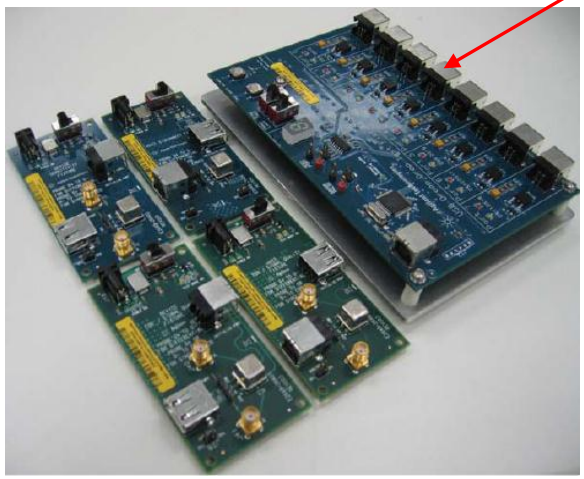
N5990A USB test solution



USB 2.0 jitter tolerance test result

Completing the Solution: Fixtures and probing

Automated drop/droop



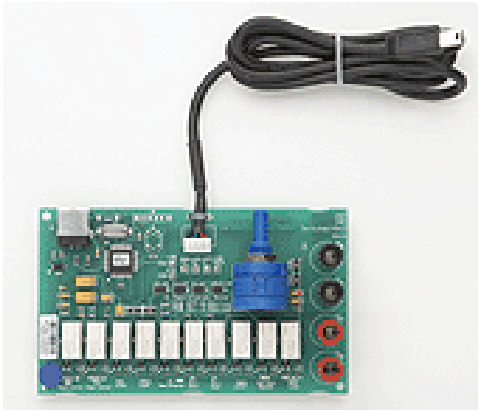
E2649A High speed USB compliance test fixture set

InfiniiMax Differential Probes:
- The world's best probing system
- The right BW for the job

N2774A Current Probe

9000 Series ships standard with N2873A probes

E2646A SQiDD fixture
- FS/LS Signal quality, Inrush



N5417A USB OET

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Design Challenges

- HS Signal Integrity
  - Trace and Driver Impedance
  - Proper decoupling
- Current Draw
  - Operating current
  - Unconfigured current
  - Suspend current
- Receiver Testing
- Test Modes

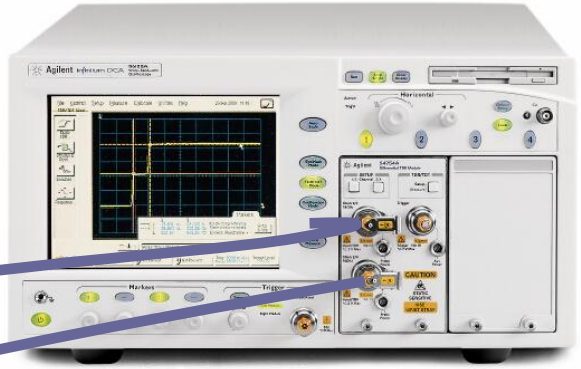
USB Impedance Spec Explained

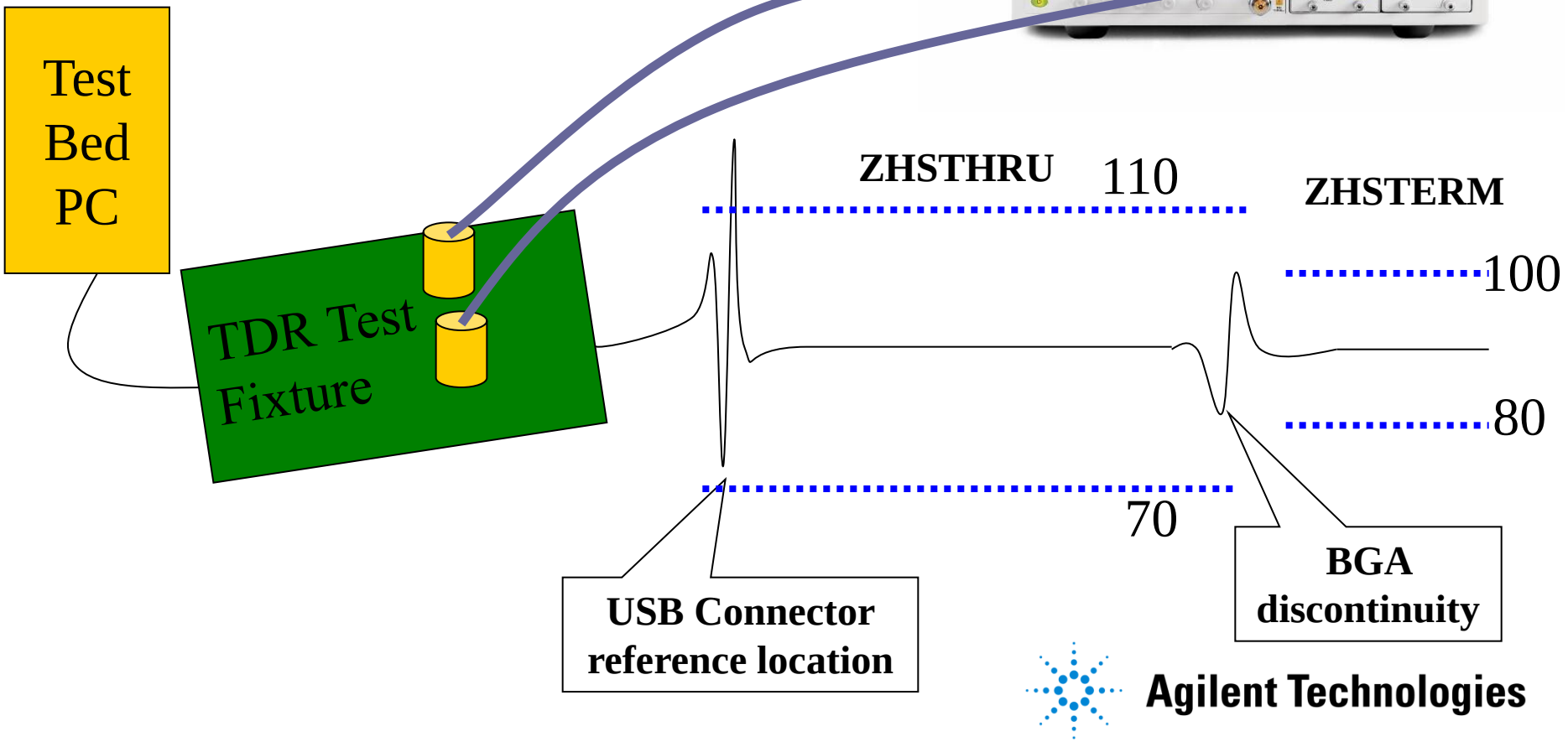
- What does the spec say?
- High-Speed Zo
  - $Z_{o\ –\ cable}$ = 90 +/-15 %
  - Z_{HSTERM} = 80 to 100 ohms differential
  - Z_{HSTHRU} = 70 to 110 ohms differential
- FS Driver Impedance
  - Not HS capable: Zdrv = 28-44 ohms
  - HS Capable: Zdrv = 40.5-49.5 ohms

USB Impedance Measurement

- 86100C DCA-J paired with

54754A Differential TDR module





Proper Decoupling

- **Prevent signal integrity problems by understanding how to properly decouple power and grounds on your chip**
- **Bulk vs filter capacitance**
  - **Electrolytic Bulk Capacitance**

    C = I / (dV/dt), size in uF depends on max transients

    For example: I peak = 3A, Vnom = 3.3V, 10% V tolerance, 10usec delta time

    C = 3A*(10us/(3.3V*0.10) = 90.9uF => use 100uF Bulk cap*

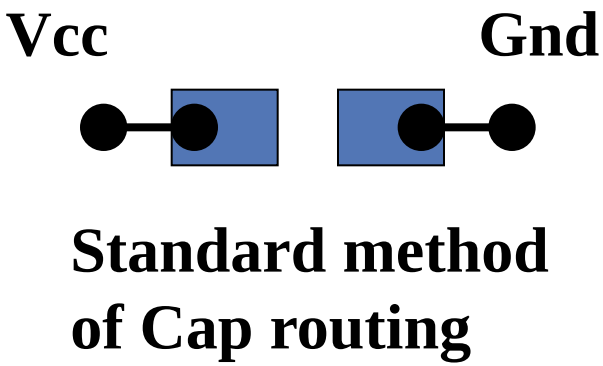
  - **Ceramic High Frequency Capacitance**

    Typical values are 0.01uF, 0.1uF to 1uF depending on filtering frequency needed

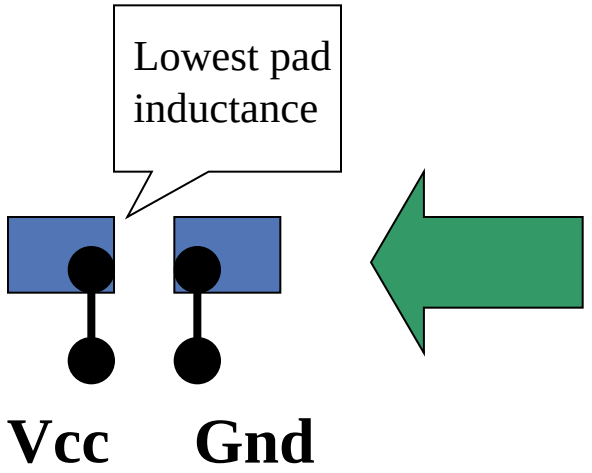
*note: Devices are required to limit inrush on hot attach by limiting load to 10uF in parallel with 44ohms.

Proper Cap Selection and routing

- Proper route/placement of capacitors
- Choose the right kind of capacitor depending on it's purpose
  - NPO (lowest ESR), X7R, X5R, Y5V



Standard method of Cap routing



Much smaller ground loop

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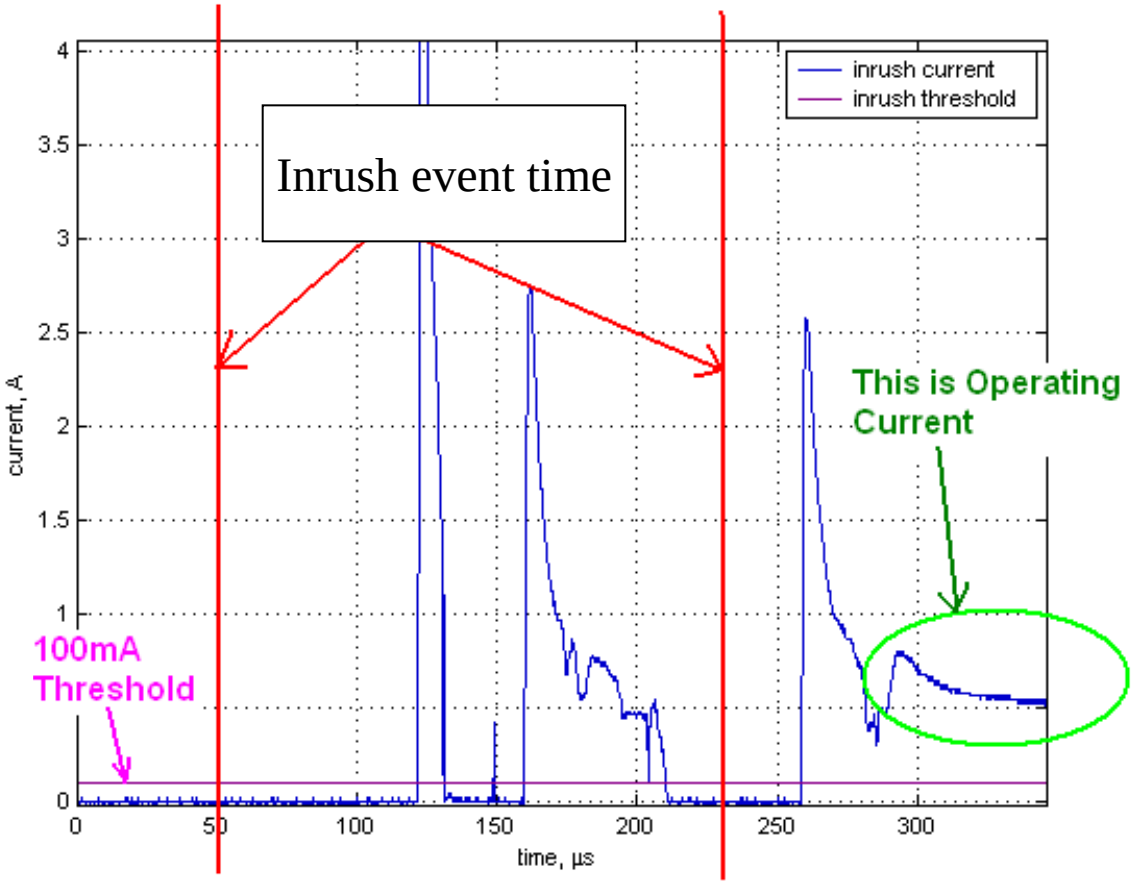
Measuring Device Inrush Current

- Inrush is a function of device load on hot attach and hub port voltage/ESR

•Spec limit = ~50uC
•Inrush waiver built in to scripts
•Limit inrush events by using sequential power on for controller logic

N2774A Current Probe



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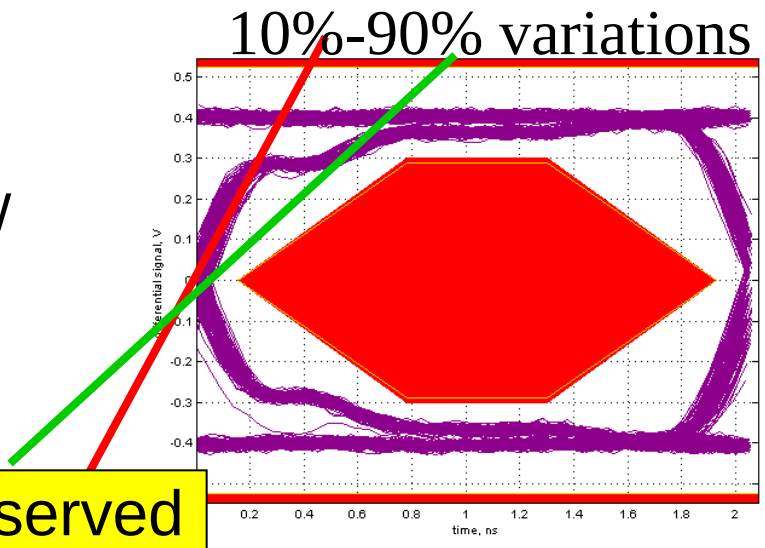
Rise and Fall time

- As designs move to smaller process technology the edge rates are increasing
- USB 2.0 specification limits RT/FT to 500ps as measured at 10%-90%
- Errors in consistency of these measurements due to:
  - Shape of signal edge
  - Noise
  - Amplitude variations
  - Probe peaking due to insufficient BW
- Slow corners give 10/90 rise time that is slower than actual edge rate
- RT/FT faster than 400ps have observed



- Oscilloscope AND Probe BW must be at least 2.5Ghz to accurately observe and measure these fast edges

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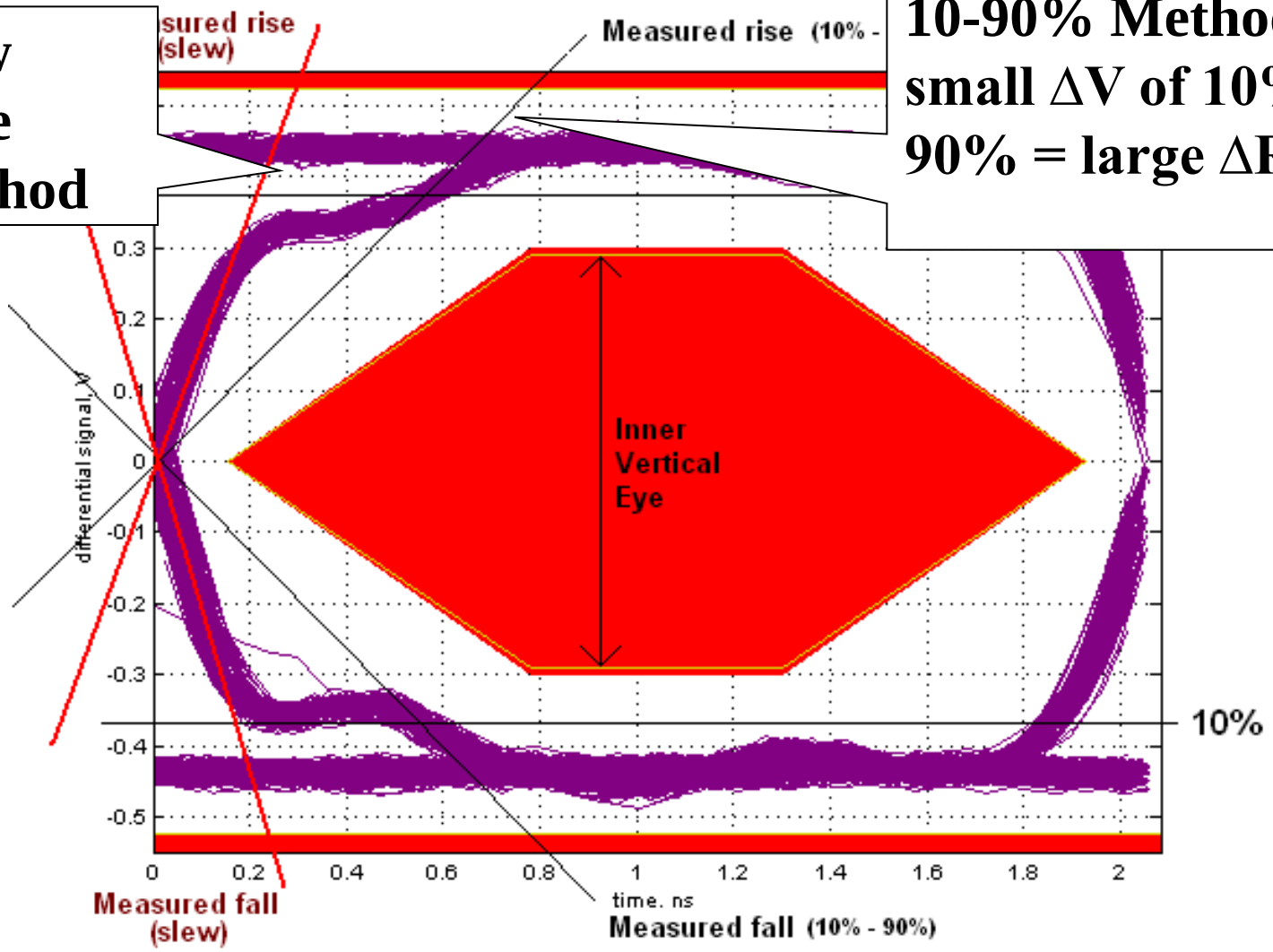
Slew rate RT/FT methodology

Slew Rate Method

10-90% Method
small ΔV of 10% and 90% = large ΔRT/FT



Refer to http://compliance.usb.org/index.html for the latest compliance test updates

Test Modes

- Test_SEO_NAK
  - Receiver test mode
- Test_J
- Test_K
- Test_Packet
- Other tests driven by HSET using normal USB device requests
  - Example: suspend, resume, reset, etc

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Compliance Pitfalls

- Failure to properly support USB suspend
  - Low power state required of all devices
    - < 2.5mA (spec says 500uA = auto waiver)
- Improperly report bus vs self powered if battery powered
- RX Sensitivity failure vs Squelch
- Backdrive
- SW Driver loading sequence
- Test mode not implemented

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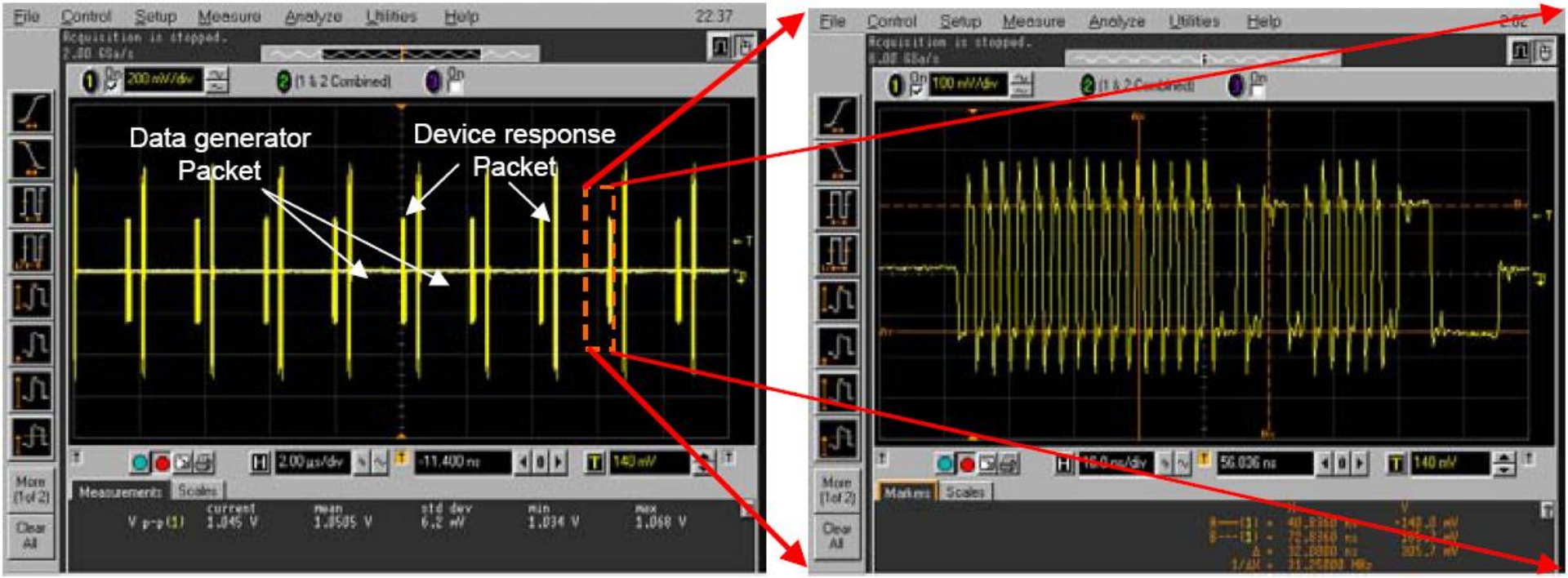
Compliance Pitfalls – RX Test



•Misinterpretation of RX sensitivity and Squelch requirements has caused considerable confusion and discrepancy in test results

•As you can see from the waveform at the right the artifacts on the transition and non-transition bits due to reflections are significant

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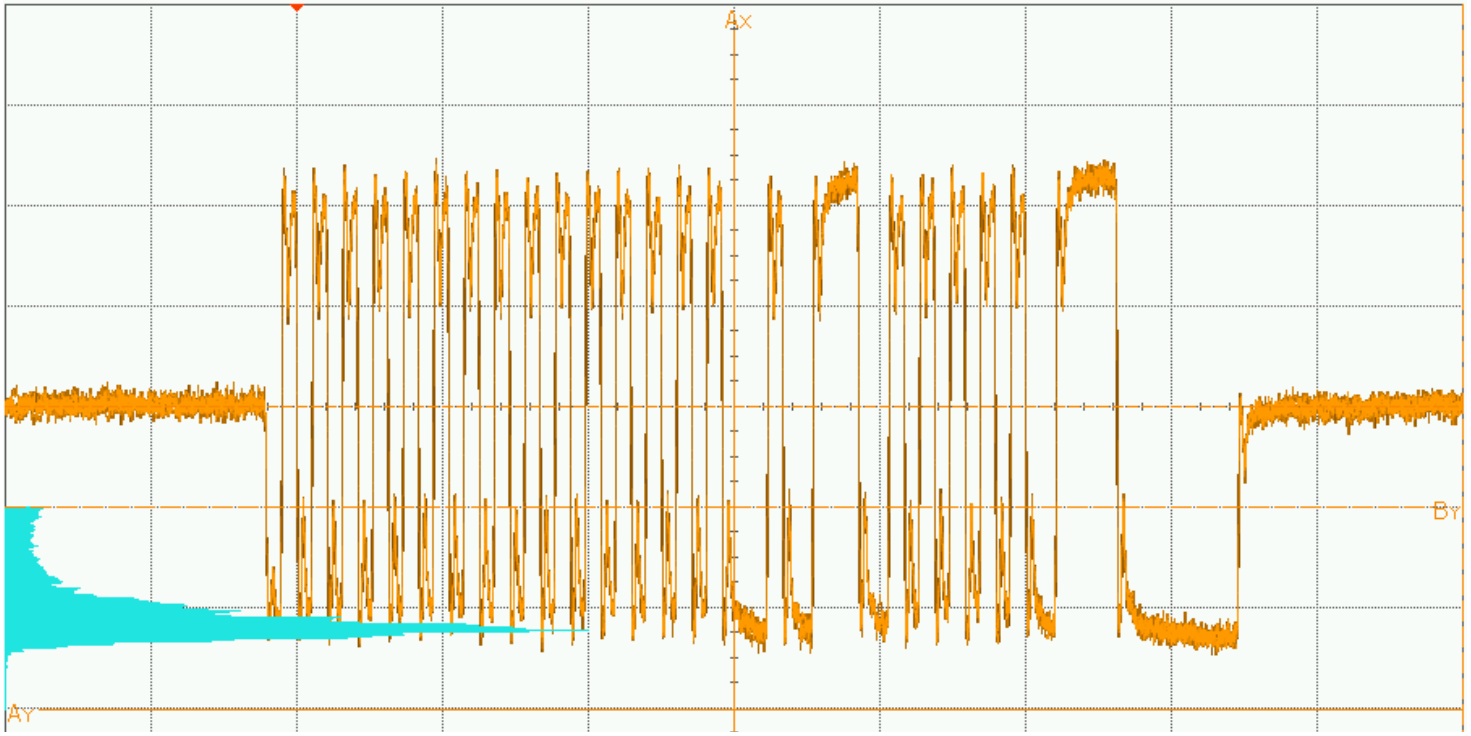
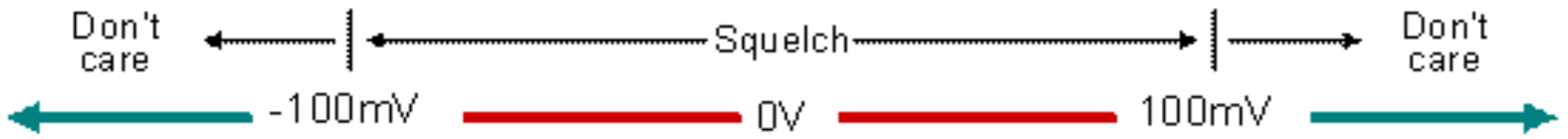
Compliance Pitfalls – RX Test

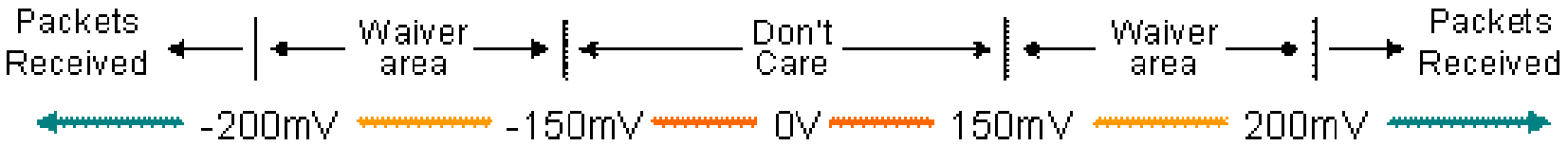


- Agilent uses a histogram function to standardize measurement of sensitivity and squelch thresholds
- Other solutions require manual placement cursors based on “flat spot” on waveform
- This automation greatly improves consistency of test results at workshops and test labs

Receiver Sensitivity (EL_17) and Squelch (EL_16)



EL_16 Squelch



EL_17 Receiver Sensitivity

•Please note that it is the combination of EL_16 and EL_17 that validates the "transmission detection envelope" defined in section 7.1.4.2 of the USB 2.0 Specification

Outline

- USB 2.0 Basics
- Agilent's USB 2.0 Solution
- Design challenges
- Common compliance pitfalls
- What are Waivers?
- Advanced Debug and Testing with the 9000 series Oscilloscope
- Conclusion / Q&A

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Waivers

- Some failures are due to measurement errors or non-critical failures
- It is important to understand how the USBIF handles some types of failures
- Automatic waivers
  - Always granted
  - May be built into test tools
- Conditional waivers
- Permanent waivers

Non-Critical = No End User Impact

Waivers

- The criterion for granting a waiver varies greatly and tends to be specific to the device. Some general factors used to consider granting or denying waiver requests are:
  - Violation's effect on end-user experience
  - Violation's affect on other USB product
  - Market share of affected product
  - Cost of corrective action to the vendor

- Waiver decisions are at the discretion of the USB-IF Compliance Chairman and members of the Certification Review Board.

Waivers

- Products with waivers post to IL and receive logo usage rights
- General USBIF rule is waivers are not published
- Design to specification not to waiver limits

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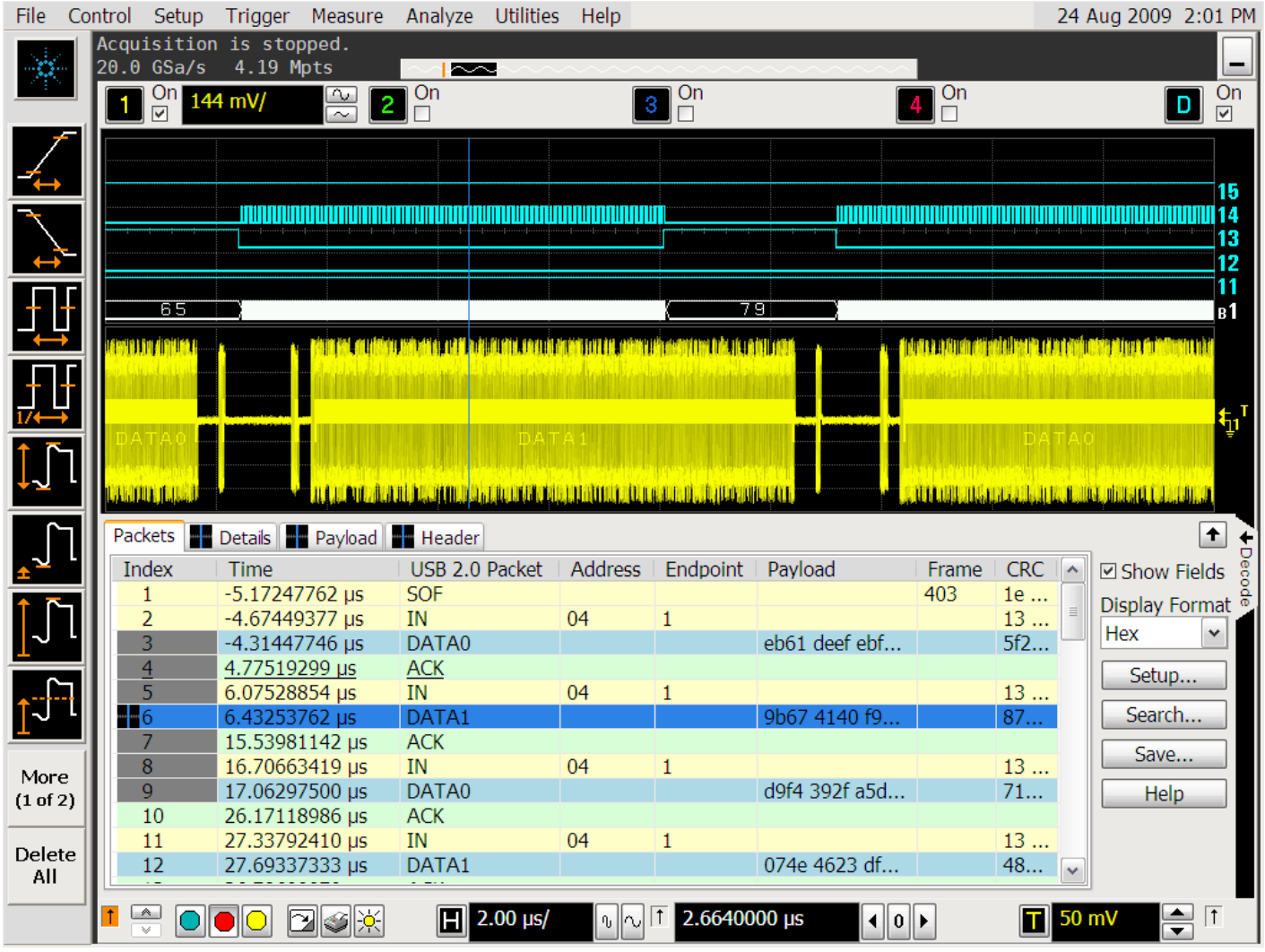
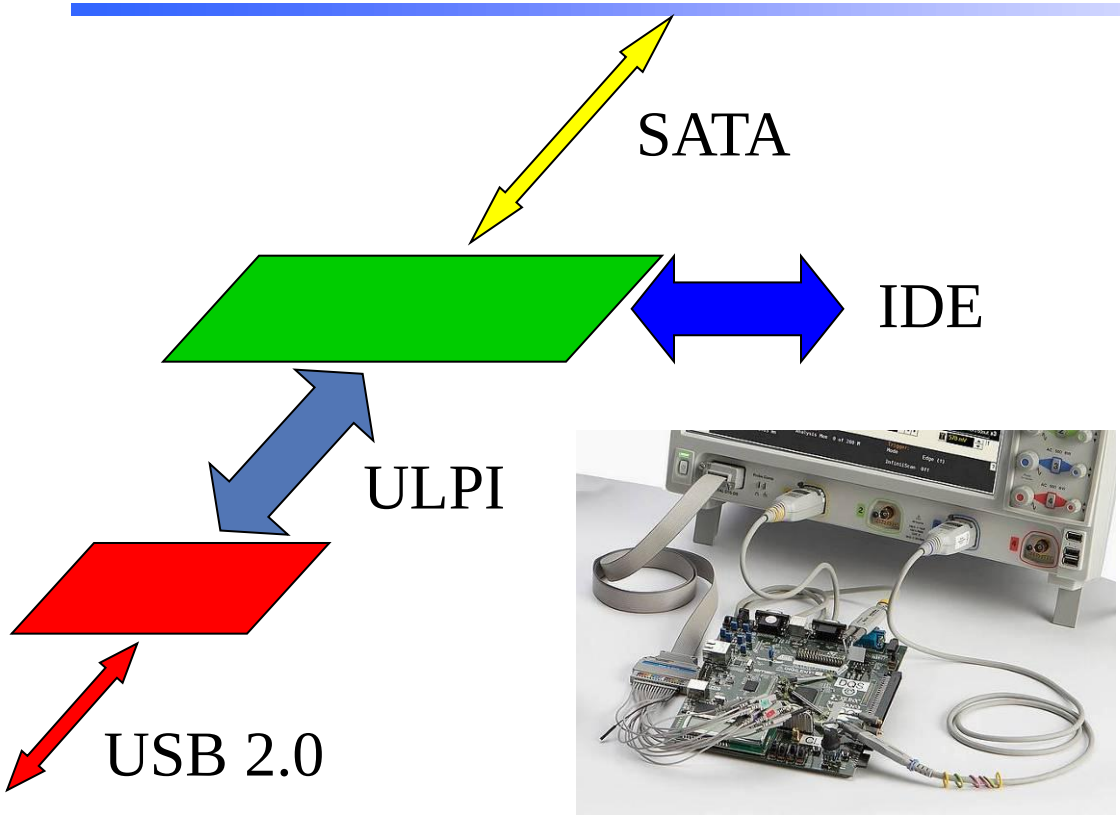
USB Protocol Triggering and Decode

- Industries first on-scope USB protocol triggering and decode capability

- **Debug protocol issues**
- **Trigger on different packet types**
- **Test embedded designs**
- **Isolate logical from electrical issues**



Testing a Complex Bus Topology with the Agilent Infiniium 9000 Scope



In today's world many subsystems are tightly integrated into multi function Embedded products:

- **USB 2.0 interface**
- **IDE parallel interface**
- **SATA interface**

Best 3-in-1 Instrument

Scope:
- Up to: 4 GHz BW, 20 GSa/s, 1 Gpts
- Powerful triggering
- Packed with rich features/analysis.

Logic Analyzer:
- 16 integrated channels
- 128 Mpts std memory, up to 2 GSa/s
- Precise analog + digital triggering

Protocol Analyzer:
- I2C, SPI, CAN, RS-232/UART, USB, PCIe, 8B/10B
- HW trigger and decode
- First scope with multi-tab viewer
- .Phy to protocol time correlation

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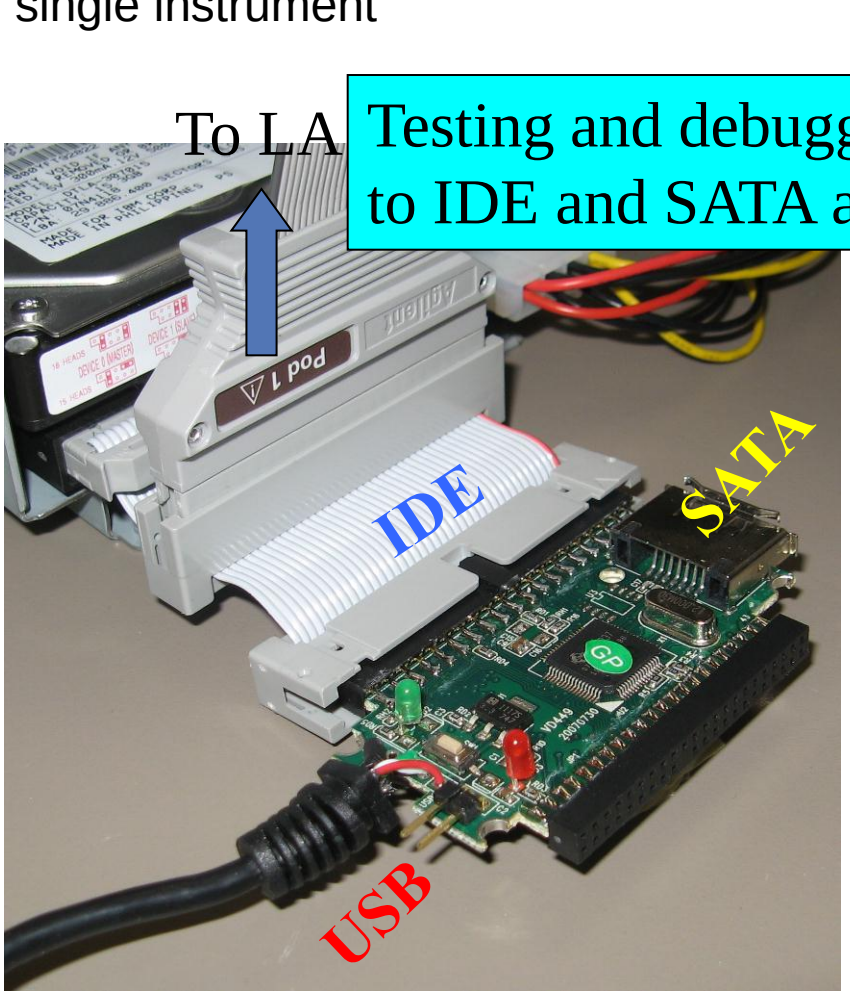
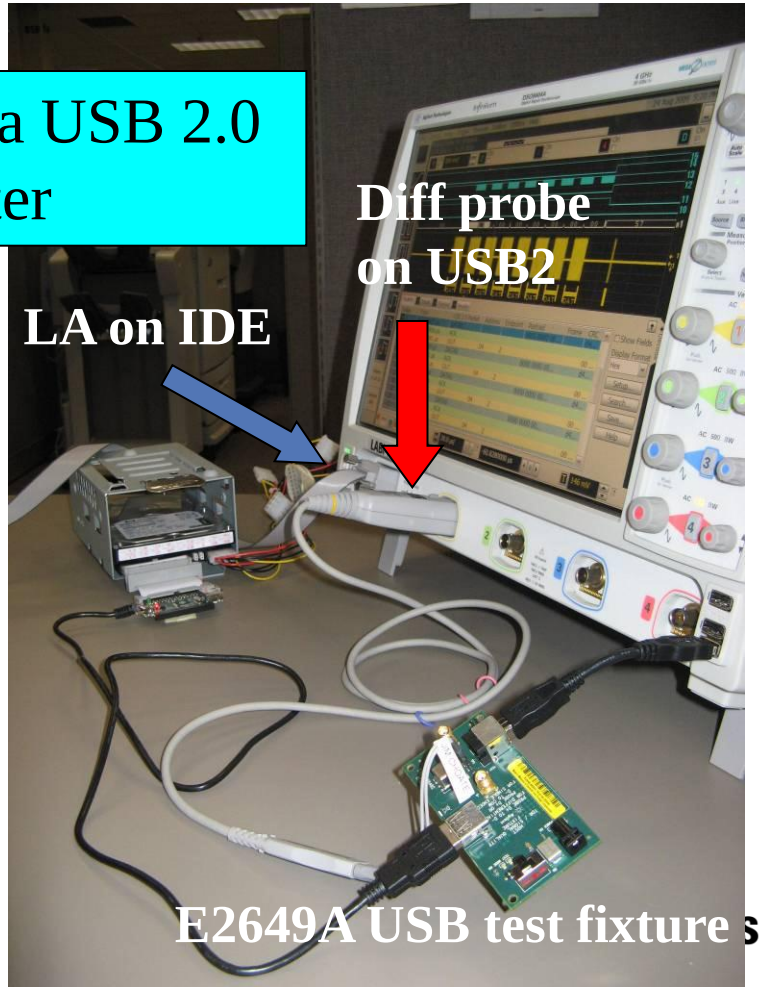
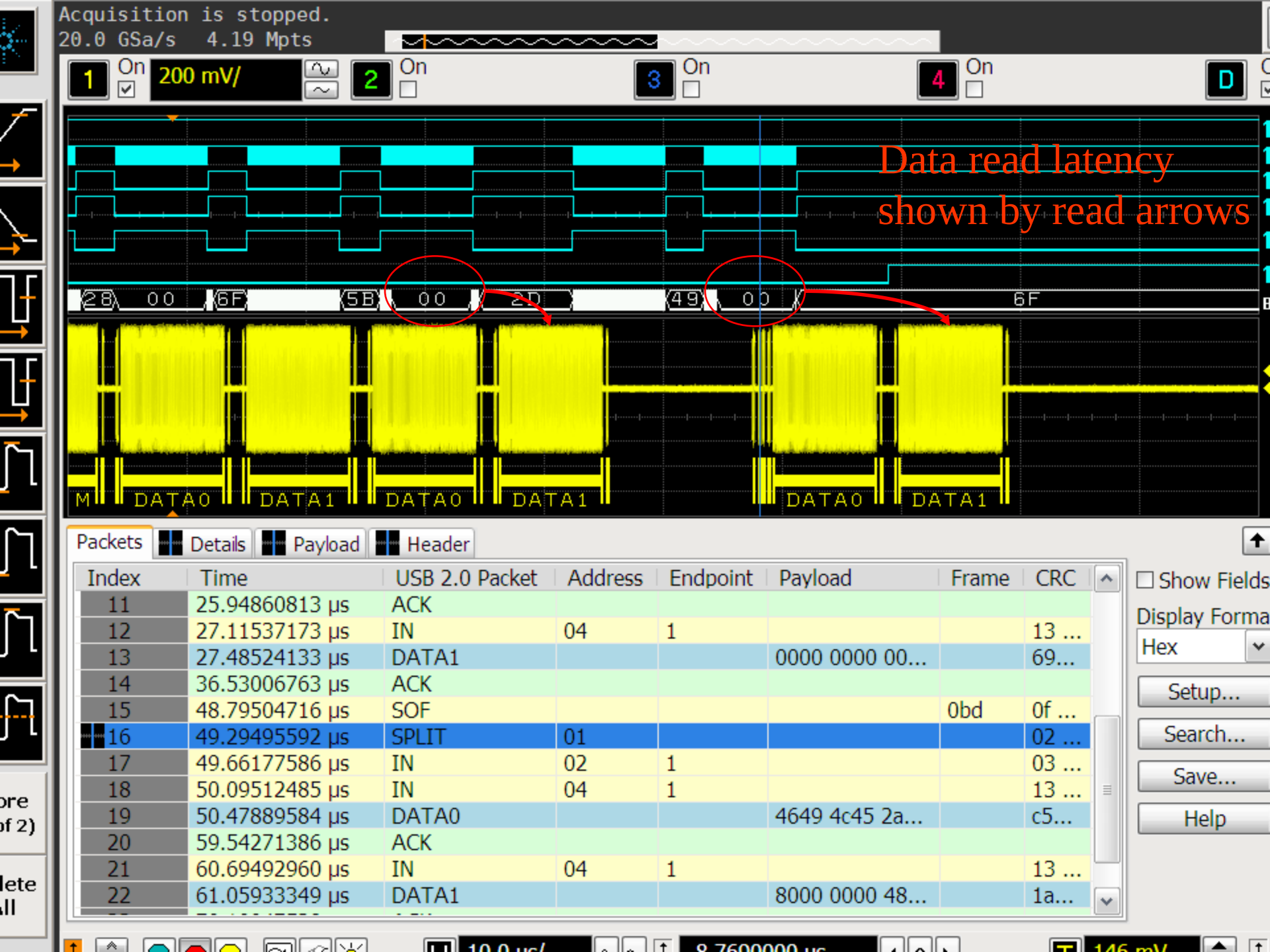
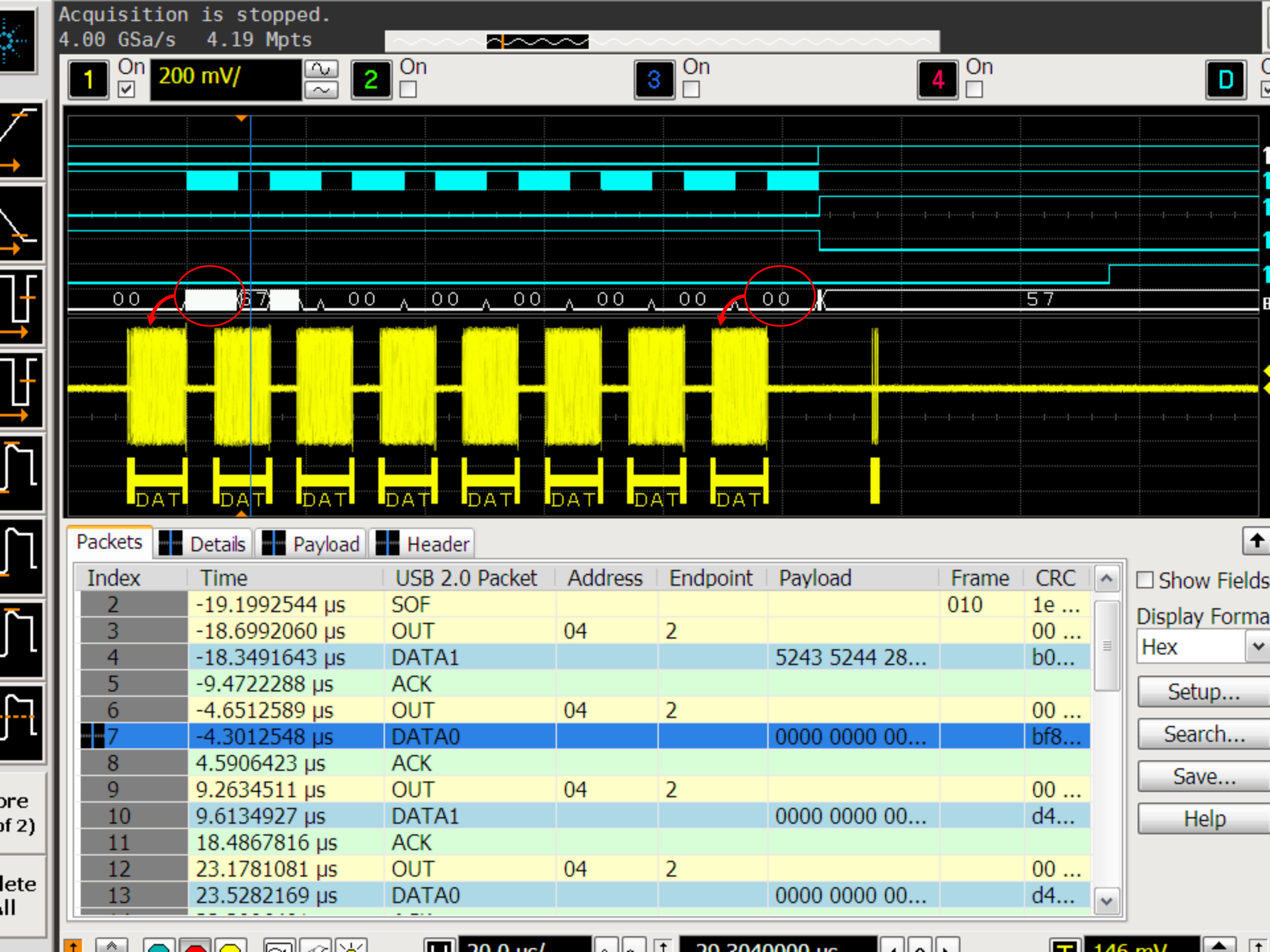
Debugging multiple bus interfaces

- In the past each interface would need to be tested separately often with different types of equipment
- Today you can use the 9000 series oscilloscope to test it all with a single instrument



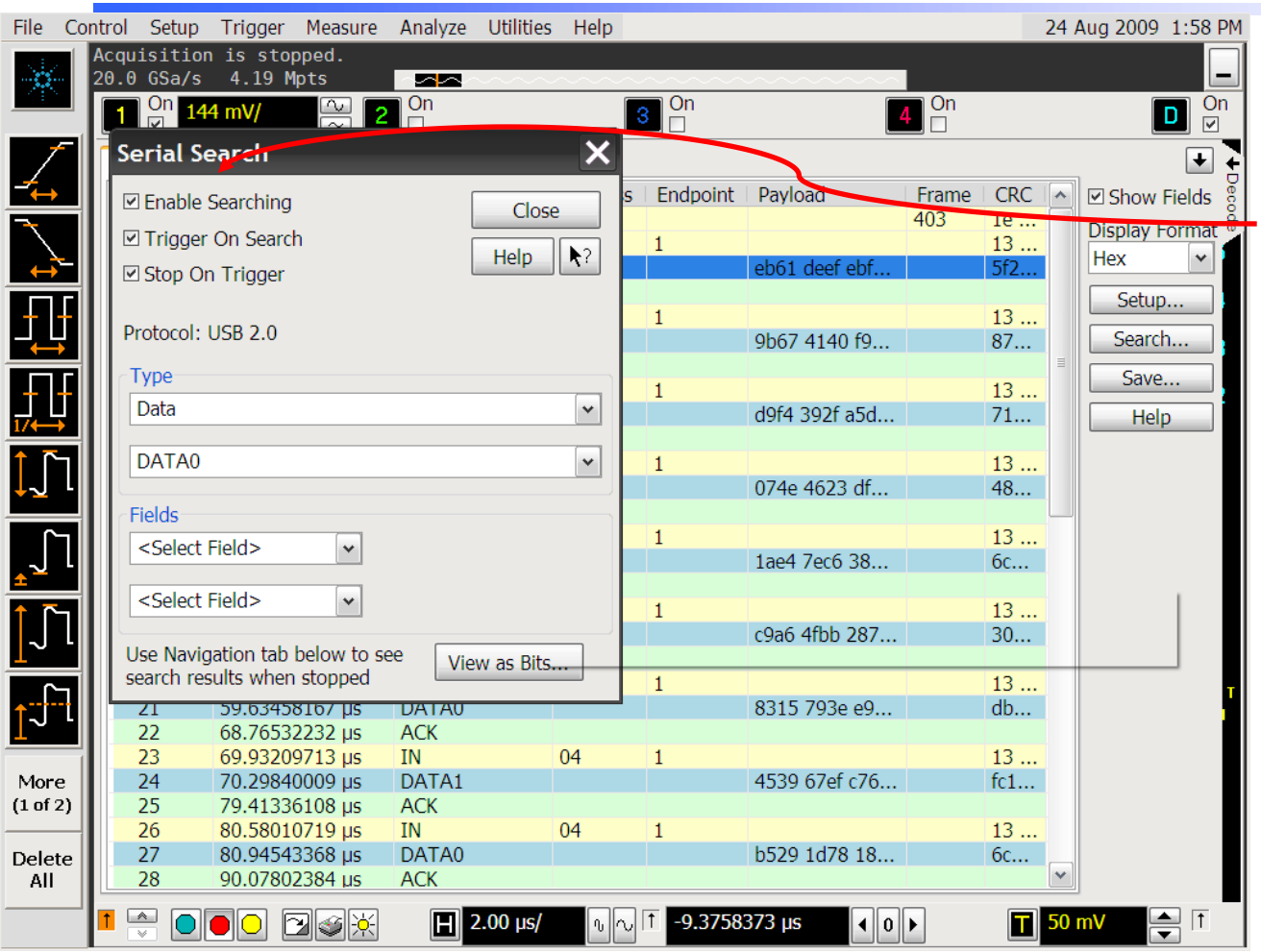



Acquisition is stopped.
20.0 GSa/s 4.19 Mpts
1 On 200 mV/
2 On
3 On
4 On
D
Data read latency
shown by read arrows
28 00 6F 5B 00 2D 49 00 6F
M DATA0 DATA1 DATA0 DATA1 DATA0 DATA1
Packets
Details
Payload
Header
Index Time USB 2.0 Packet Address Endpoint Payload Frame CRC
11 25.94860813 µs ACK
12 27.11537173 µs IN 04 1 13 ...
13 27.48524133 µs DATA1 0000 0000 00... 69...
14 36.53006763 µs ACK
15 48.79504716 µs SOF 0bd 0f ...
16 49.29495592 µs SPLIT 01 02 ...
17 49.66177586 µs IN 02 1 03 ...
18 50.09512485 µs IN 04 1 13 ...
19 50.47889584 µs DATA0 4649 4c45 2a... c5...
20 59.54271386 µs ACK
21 60.69492960 µs IN 04 1 13 ...
22 61.05933349 µs DATA1 8000 0000 48... 1a...
Show Fields
Display Forma
Hex
Setup...
Search...
Save...
Help


Acquisition is stopped.
4.00 GSa/s 4.19 Mpts
1 On 200 mV/
2 On
3 On
4 On
D
00 57 00 00 00 00 00 00 57
DAT DAT DAT DAT DAT DAT DAT DAT
Packets
Details
Payload
Header
Index Time USB 2.0 Packet Address Endpoint Payload Frame CRC
2 -19.1992544 µs SOF 010 1e ...
3 -18.6992060 µs OUT 04 2 00 ...
4 -18.3491643 µs DATA1 5243 5244 28... b0...
5 -9.4722288 µs ACK
6 -4.6512589 µs OUT 04 2 00 ...
7 -4.3012548 µs DATA0 0000 0000 00... bf8...
8 4.5906423 µs ACK
9 9.2634511 µs OUT 04 2 00 ...
10 9.6134927 µs DATA1 0000 0000 00... d4...
11 18.4867816 µs ACK
12 23.1781081 µs OUT 04 2 00 ...
13 23.5282169 µs DATA0 0000 0000 00... d4...
Show Fields
Display Forma
Hex
Setup...
Search...
Save...
Help

Acquisition is stopped.
20.0 GSa/s 4.19 Mpts
1 On 200 mV/
2 On
3 On
4 On
D
RESET
READY
RD_
WR_
REQ
IntQ
28 00 6F 5B 00 2D 49 00 6F
DATA0
Decode
M DATA0 DATA1 DATA0 DATA1 DATA0 DATA1

Advanced protocol triggers for debugging



The serial search and real time HW trigger capabilities open a new realm of debug capabilities

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Summary

- USB compliance testing has grown over the years to address real product problems
- Agilent has been a key partner with the USBIF in the growth and phenomenal success of the USB compliance test program
- Agilent offers everything you need to test and certify all of your USB products
- The N5416A USB Test Option offers the most accurate and highest level of USB test automation in the industry today
- Agilent's N5990A test automation sw takes testing to the next level with full USB 2.0 jitter tolerance characterization
- The Infiniium 9000 Series is the best 3-in-1 instrument with scope, logic analyzer, protocol analyzer test capabilities

Agilent Delivers the Worlds Best USB Test Solutions

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Additional Information

- Go to www.usb.org to get additional information on certifying your USB products
- For specific updates to compliance requirements go to http://compliance.usb.org/index.html

- Agilent Application Note: Debugging USB 2.0: It's Not Just a Digital World
- Go to www.agilent.com/find/usb to find more about Agilent Superior Signal Integrity Solutions and Probing for Your Applications

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Miscellaneous topics

- Workshops
  - Very good place for hands on training
  - Talk to experts
- USBET – required for compliance, integrated into Agilent's sw solutions
- HSET tool issues – supports Win7/8 with by disabling signed driver requirement (F8 on boot)
- Fixture standardization
  - USBIF will soon require probe less test method – using only SMA probing.
  - Agilent fixtures support this now.